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著者	Hirata Kunio
journal or publication title	The bulletin of the Marine Biological Station of Asamushi, Tohoku University
volume	7
number	2-4
page range	89-99
year	1955-03-30
URL	http://hdl.handle.net/10097/00130937

BULLETIN OF THE MARINE BIOLOGICAL STATION OF ASAMUSHI,
VOL. VII, NOS. 2, 3, and 4. 1955

THE EXISTING AND RAISED CORAL REEFS IN YORON ISLAND AND THEIR SHELL BEARING MOLLUSCS*

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(With 2 figures)

INTRODUCTION.

A scientific survey of the Amami-Oshima Group was carried out from the 17th of May to the 1st of June 1954 by the staff of the Kagoshima University. The present writer took part in the survey as a member of biological section, and made an investigation on the distribution of the shell bearing molluscs on the coral reef of Amami-Oshima, Kikaiga-shima, Tokuno-shima, Okinoerabu-jima and Yoron-jima (Yoron Island). Afterwards, from the 7th to the 22nd of August the present writer made the second survey exclusively on Yoron Island by himself.

Yoron Island is circumscribed by beautiful barrier reefs which characterize the island and is covered with raised coral reefs. It had been left outside of scientific investigation till the present surveys. This note is a preliminary report about the study on the recent and raised coral reefs of Yoron Island.

RECENT CORAL REEF.

Most of the recent coral reefs of Yoron Island are barrier reefs and some are fringing. Barrier reefs are beautifully represented on east, north and west sides of the island and fringing reefs on the southern coast. The barrier reef is formed along coast line with a proper gentle dip. The width of the lagoon becomes smaller as the dip of the slope becomes larger, and at last diminishes to zero, resulting in the formation of a fringing reef.

About the formation of the barrier reef, three hypotheses have been advocated. According to Darwin, the barrier reef is first formed as a fringing reef, which is converted into the former by the subsidence of the land. Against this subsidence theory, Vaughan advocated submergence theory. The lowering of sea-level

* Dedicated to Professor Emeritus Dr. Shinkishi Hatai, the founder of the Marine Biological Station of Asamushi.

during glacial ages and its rise during interglacial were firmly ascertained by many modern geologists.

The third hypothesis advocated by Hobbs (1923) is based on the differential uplift and subsidence observable in the mountain arc, uplift of the front side and subsidence of the back side of the arc. This theory also starts from the fringing reef which is raised up in the front side to form a raised coral reef and is subsided in the back side to form a barrier reef. He explained the coral reef in Sunda and Marianne Arc as excellent examples of this type of reef formation.

Yoron Island is an islet which is one of the members of Ryukyu Arc. But here no proof of differential uplift and subsidence of land was observable. Also, it is not necessary to take up the subsidence or the submergence as fundamental factors of the barrier reef formation in Yoron Island.

In this barrier reef, the outermost part of the reef grows out into sea for about 10 meters in the form of comb teeth (Fig. 1, III and IV) along the edge of which living corals are found. Next, bases of the teeth unite with each other to form continuous flat surface. This area is about 15 meters in width (Fig. 1, II). Depressions are found here and there to form tide pools in which living corals are growing. These depressions are the remains of the spaces between old teeth. Next, the surface is elevated a little to form the highest region of about 10–20 meters in width. These measurements should be taken as to be rather rough and variable according to places.

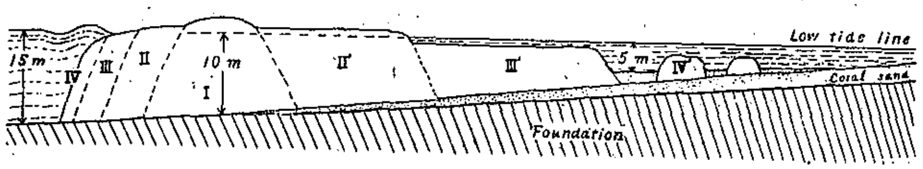

Fig. 1. Schematic illustration of a barrier reef in Yoron Island.

The part (I) may be conceived to be the part first formed. There must be some certain causes why this barrier reef was first formed at the depth of about 10 meters. And one of the causes must be the severe disturbance caused by waves in the shallow sandy water. Coral likes the sunshine and it was reported by Vaughan (1923) that it does not flourish in shadow. So, coral cannot flourish at the bottom of too deep dark water. These two may be considered as the most important factors which were necessary for the formation of the barrier reef of Yoron Island along the line of 10 meters in depth.

Part II' has a flat surface with the same level with II. According to Vaughan (1923), coral grows by far more rapidly in the calm water than in the wavy open-sea. Once shut in by the part (I) from the wavy open sea, coral grows rapidly in the lagoon. This is the reason why part II' is by far wider than part II. The

same can be said about the part III and part III', the surfaces of which are mostly under the low tide.

Further, one more important fact must be noticed concerning the form of the reef represented in Fig. 1. It is the fact that there occurred two slight uplifts of the land or slight lowerings of the sea level since the first barrier reef (part I) attained the sea surface; both less than one meter, maybe a half meter or so. Furthermore, it is said that glaciers reached a maximum in the nineteenth century and since that time have been shrinking at a very rapid rate and Gutenberg (1941) statistically showed the rise of sealevel of about 2.5 inches during the last one hundred years. Consideration about these facts may facilitate the understanding of the barrier reef of Yoron Island.

In lagoon, there are many living coral masses of irregular form under low tide level. And even a ship of 250 tons anchored on the open sea, 2 miles off Chabana, which is the only anchorage of the island. It was only 20 meter in depth at the anchoring place.

DISTRIBUTION OF THE SHELL BEARING MOLLUSCS ON THE SURFACE OF THE BARRIER REEF.

The whole surface of this barrier reef can be divided into three regions according to the fauna of the shell bearing molluscs.

The outermost region (Fig. 1, I, II and III) is covered with a lot of algae. In this part, Muricidae (especially *Drupa morum*, *D. albolabris* and *D. granulata*), Mitridae (especially *Mitra decurtata* and *M. litterata*), and *Ravitrona caputserpentis* are found most abundantly. All six species belonging to Iga-reishi (Nom. jap.) are found (from No. 1 to No. 6 of the following list), especially *Drupa morum* and *D. albolabris* being abundant. This region can be said to be characterized by these species and may be called the *area of Drupa*.

The greater part of II' in Fig. 1 is covered with thin layer of sand, one or two centimeters in thickness, which has been brought up by waves, whereas in the outer region it has been washed away also by waves. The sand gives a profound effect to the fauna of this region. *Conus*, especially *C. lividus*, *C. flavidus* and *C. ebraeus*, and *Strombus urceus* flourish instead of *Drupa*. And the inner half of this region are densely crowded with *Volsella auriculata* (Ryukyu-hibari-gai). Algae diminish both their amount and variety and small green algae are found scattered all over the surface. This region may be called *Conus region*.

The third and innermost part (III' in Fig. 1) of the reef is always under water. The surface is naked, lacking algae and is crowded with sea-urchin, *Echinometra mathaei*, *Heliocidaris crassispina*, *Tripneustes gratilla*, and *Heterocentrotus mamillatus* and some Ophiurida. In this area molluscs are not abundant. They are found in an extremely small density, only some species in the outerzone migrating to this area (*cf.* List of Species). The only species which was found exclusively in this region was *Hydatina physis* and that only two individuals.

LIST OF SPECIES AND NUMBER OF INDIVIDUALS COLLECTED.

The following list is arranged in the order of families with more abundant number of individuals concerning the outermost *Drupa* region. Figures in the last three columns represent the number of individuals collected. The time spent for the collection of each regions was: *Drupa* region for an hour, *Conus* region for an hour and sea-urchin region for half an hour. The species names are taken from the Check List by Kuroda and Habe (1952).

	List of species (Nomina japonica in parentheses)	Number of individuals		
		Drupa region	*Conus* region	Sea-urchin region
	Fam. Muricidae			
1.	*Drupa morum* (Röding) (Murasaki-iga-reishi)	279	12	0
2.	*D. albolabris* (Blainville) (Shiro-iga-reishi)	92	4	2
3.	*D. spathulifera* (Blainville) (Aka-iga-reishi)	13	19	0
4.	*D. rubuscaesium* Röding (Hirokuchi-iga-reishi)	5	0	0
5.	*D. ricina* (Linné) (Kimadara-iga-reishi)	4	4	2
6.	*D. grossularia* Röding (Kiiro-iga-reishi)	2	9	0
7.	*D. granulata* (Duclos) (Reishi-damashi)	355	54	17
8.	*Drupella cornus* (Röding) (Shiro-reishi-damashi)	9	1	0
9.	*Purpura tuberosa* (Röding) (Tsuno-reishi)	6	8	2
10.	*P. kieneri* Deshayes (Tsuno-tetsu-reishi)	4	6	0
11.	*P. intermedia* Kiener (Koibo-tetsu-reishi)	2	1	0
12.	*Nassa francolinus* (Bruguière) (Hanawa-reishi)	0	1	0
	Fam. Mitridae			
13.	*Mitra decurtata* Reeve (Futokoro-yatate)	192	22	0
14.	*M. litterata* Lamarck (Midare-shima-yatate)	41	18	2
15.	*M. zebra* Lamarck (Ko-shima-yatate)	12	9	5
16.	*M. virgata* Reeve (Chyu-shima-yatate)	9	6	0
17.	*M. retusa* Lamarck (O-shima-yatate)	6	5	0
18.	*M. chrysalis* Reeve (Mayu-fude)	1	5	1
19.	*M. stictica* (Link) (Nishikino-kiba-fude)	0	4	0
20.	*Pusia cancellarioides* (Anton) (Arare-otome)	2	6	0
21.	*Vexillum exasperatum arenosum* (Lamarck) (Hama-zuto)	0	1	0
22.	*V. pacificum* (Reeve) (Chijimi-hamazuto)	1	1	0
	Fam. Cypraeidae			
23.	*Ravitrona caputserpentis* (Linné) (Hanamaruyuki)	77	19	1
24.	*Monetaria monetoides* Iredale (Kiiro-dakara)	1	34	2
25.	*M. annulus* (Linné) (Hanabira-dakara)	1	1	0
	Fam. Conidae			
26.	*Conus lividus* Bruguière (Iboshima-imo)	5	93	3
27.	*C. flavidus* Lamarck (Kinukatsugi-imo)	19	68	2
28.	*C. ebraeus* Linné (Madara-imo)	5	41	5
29.	*C. chaldaeus* (Röding) (Ko-madara-imo)	1	1	0
30.	*C. rattus* (Hairo-miñashi)	0	1	0
31.	*C. sponsalis* Bruguière (Hanawa-imo)	26	32	0
32.	*C. fulgetrum* Sowerby (Sayagata-imo)	1	10	0
33.	*C. coronatus* Gmelin (Juzukake-sayagata-imo)	0	3	0
34.	*C. catus* Bruguière (Arare-imo)	1	5	0
	Fam. Strombidae			
35.	*Strombus urceus* Linné (Mukashitamoto)	3	168	1
36.	*S.* lentiginosus Linné (Ibosode-gai)	0	1	0
37.	*S. luhuanus* Linné (Magaki-gai)	0	1	0
38.	*Lambis lambis* (Linné) (Kumo-gai)	0	2	0
	Fam. Vasidae			
39.	*Vasum turbinellum* (Linné) (Ko-onikobushi)	17	13	0
	Fam. Trochidae			
40.	*Trochus stellatus* Gmelin (Murasaki-uzu)	13	17	0
41.	*T. calcaratus* Souverbie (Hakusha-uzu)	3	0	0
42.	*T. maculatus* Linné (Nishiki-uzu)	1	26	0
43.	*Tectus maximus* (Philippi) (Sarasabatei)	0	2	0
	Fam. Bursidae			
44.	*Bursa bufonia* (Gmelin) var. (Okinishi)	9	12	0
45.	*B. corrugata* (Perry) (Unebora)	0	1	0
	Fam. Cymatidae			
46.	*Cymatium nodulus* (Link) (Shio-bora)	0	6	0
47.	*C. nicobalicum* (Röding) (Mitsukado-bora)	0	2	1
48.	*C. aquatile* (Reeve) (Satsuma-bora)	0	1	0
	Fam. Muricidae			
49.	*Murex rubicundus* (Perry) (Ganzeki-bora)	0	1	1
	Fam. Turbinidae			
50.	*Turbo stenogyrus* Fischer (Koshidaka-sazae)	2	1	0
51.	*T. argyrostomus* Linné (Chosen-sazae)	0	2	0
	Fam. Fasciolariidae			
52.	*Peristernia nassatula* (Lamarck) (Murasaki-tsunomata-modoki)	1	9	0
	Fam. Buccinidae			
53.	*Engina mendicaria* (Linné) (Noshi-gai)	6	19	0

54. *Cantharus fumosus* (Dillwyn) (Hora-damashi)	0	2	0
Fam. Cerithiidae			
55. *Contumax nodulosus* (Bruguière) (Onino-tsuno-gai)	0	1	0
56. *C. columna* (Sowerby) (Ko-onino-tsuno-gai)	0	7	0
57. *C. echinatus* (Lamarck) (Me-onino-tsuno-gai)	0	1	0
58. *Clypeomorus chemnitzianus* (Pilsbry) (Kuwanomi-kanimori)	0	2	0
Fam. Nassariidae			
59. *Nassarius balteatus* (Lischke) (Yofubai)	0	2	0
Fam. Hydatinidae			
60. *Hydatina physis* (Linné) (Misu-gai)	0	2	0
Fam. Mytilidae			
61. *Volsella auriculata* (Krauss) (Ryukyu-hibari-gai)	4	216	2
Fam. Pterriidae			
62. *Pinctada panasesae* (Jameson) (Midori-aori-gai)	4	16	0
Fam. Tridachnidae			
63. *Tridachnes crocea* (Lamarck) (Hime-jyako)	2	0	0
64. *T. elongata* (Lamarck) (Shiranami)	1	0	0
Fam. Chamidae			
65. *Chama semipurpurata* Lischke (Somewake-gashira)	1	3	2
Fam. Veneridae			
66. *Venus reticulata* Linné (Ara-nunome-gai)	0	2	0

DISTRIBUTION OF RAISED CORAL REEFS.

Yoron Island is a small and flat islet of 6 km (EW) × 5 km (NS). The island is divided into three parts by two dislocation lines. One line runs from the north to the south and the other from near the highest points of the island to the east (Fig. 2).

The western part is the lowest and nearly horizontal. The raised coral reefs in this part are irregularly distributed all over the area except a part along the road of Riccho and rice fields. Along the Riccho road, the exposed foundations are exclusively composed of Palaeozoic metamorphic rock (roughly shaded part in Fig. 2). Whereas, the foundation rocks of raised coral reefs found in this part are all Palaeozoic limestone (marble) of bluish gray (Fig. 2, black dots). The northern half of this part was not thoroughly studied and is left to the future investigation.

The north-eastern part makes a slope with a gentle dip towards east and north, ending in a sandy shore. This part has several tiers of raised coral reefs. The topmost raised reef is a sheet of irregular contour (Fig. 2, I). The reef No. II, III and IV run parallel to the coast line, No. III being most beautifully represented as a small mountain range. It is called "Uro-sammyaku", which

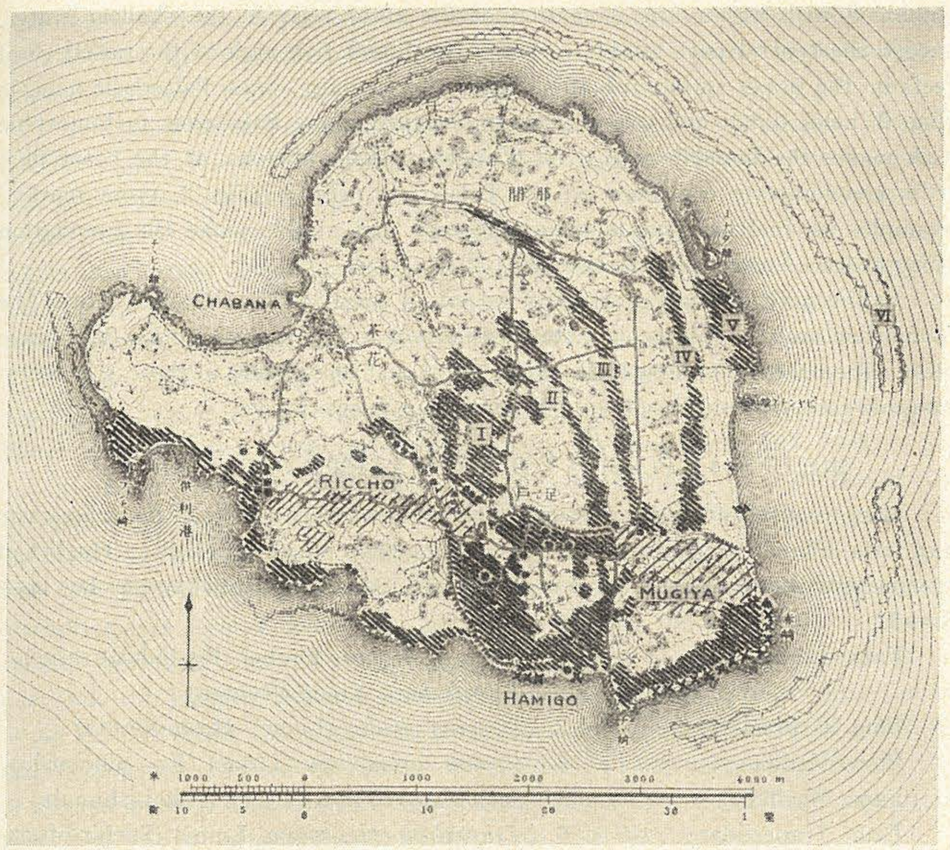

Fig. 2. Distribution of the raised coral reefs in Yoron Island. Densely shaded area: raised coral reef. Roughly shaded area: the area where lacks raised coral reef. Black dot: Paleaozoic limestone makes the foundation of the raised coral reef. Black triangle: ditto, Palaeozoic metamorphic rock. Cross: ditto, conglomerate.

means coral mountain-range. The planes intercalated between these coral elevations are cultivated as rice fields, which had been, it is certain, lagoons before each uplifts of the foundation. The northern half of this region was not studied thoroughly and is left to the future investigation.

The third region is a high terrace, makes a gentle slope towards south-east and ends at the coast line as a precipice. Raised coral reefs in this part are well developed. They are of irregular form and do not show such a beautiful arrangement as in the second region, except a beautiful terrace developed at Hamigo (Fig. 2). This is due to the fact that in this region the greater part of the reefs were formed as fringing reefs. It is a problem why in this part the barrier reef was not formed, in spite of its similar dip with the second part. The present writer wants to point out that there was no sand accumulation here, which disturbs, when combined with waves, the formation of the coral reefs in the shallow water, except the central part of this region. The foundation rock of the raised coral reefs in the upper surface of this region was in most cases Palaeozoic marble (Fig. 2, balck dots), and two cases were observed where Palaeozoic metamorphic rock makes the foundation (Fig. 2, triangle marks); whereas, at the coast line, it is conglomerate composed of the Palaeozoic pebbles (Fig. 2, cross marks), examples where Palaeozoic metamorphic rock and marble make the foundation being observed each only one case (Fig. 2).

In the northern half of Mugiya, no raised coral reef was found. Here, the foundation rock is Palaeozoic metamorphic rock. The present author will make clear the reason why there lacks raised coral reef completely in these two metamorphic rock regions, Riccho and Mugiya, in a future report.

MOLLUSCAN FOSSILS FOUND IN RAISED CORAL REEFS.

Many molluscan fossils are found in raised coral reefs. Most of them are casts and it is difficult to identify them. But some have preserved shells. The list of specimens which were identifiable is as follows. So far, no extinct species has been found.

Fam. Turbinidae	1. *Turbo stenogyrus* Fischer (Koshidaka-sazae)
	2. *T. petholatus* Linné (Ryuten)
Fam. Cypraeidae	3. *Lyncina vitellus* (Linné) (Hoshi-kinuta)
Fam. Vasidae	4. *Vasum turbinellum* (Linné) (Ko-onikobushi)
Fam. Mytilidae	5. *Lithophaga lithura* Plisbry (Kikai-ishimate)
Fam. Trapeziidae	6. *Trapezium oblongatum* (Linné) (Suehiro-funagata-gai)
Fam. Tridacnidae	7. *Tridachnes maxima* Röding (O-shiranami)
	8. *T. squamosa* (Lamarck) (Hire-jyako)
	9. *T. crocea* (Lamarck) (Hime-jyako)
Fam. Veneridae	10. *Venus reticulata* Linné (Ara-nunome-gai)

CHRONOLOGY OF THE RAISED CORAL REEFS.

H. Yabe and S. Hanzawa (1925) reported that the Ryukyu limestone was formed in the Prepleistocene epoch, against the opinion of A. Tokunaga (formerly Yoshiwara) who acknowledged the Pleistocene origin (1900). They investigated Foraminifera in the raised coral reefs, and found some species abundantly which live at the present time around the Philippines and in the southern tropical sea and not in the vicinity of Ryukyu Archipelago. Accordingly, they denied the origin of the raised coral reefs in the Pleistocene epoch, when it must have been kept at a lower temperature, glaciers prevailing. But since 1925, geological knowledges concerning the Pleistocene and Alluvial epoch has been advanced and renewed in many points (Flint, 1952). Therefore, some discussion must be added about this problem. The facts which are related with the chronology of these raised coral reefs may be summarized as follows.

1. During the period from 8,000 to 6,000 years ago, it was warmer than the present time. The raised coral reefs at Tateyama in Chiba Prefecture, Japan, was constructed during this period. In this warm period, the sea-level was uplifted higher than at the present time. Accordingly, it is probable that the coral reef which was formed during this period must be situated on a higher level than the present sea-level. And in Yoron and other Ryukyu islands, it is highly probable that the raised coral reef now situated along the coast line (Fig. 2) must be the reef which have been formed in this period. The raised coral reef in this position was reported to have grown more rapidly than that in the higher position and the recent corals, the latter two having grown with nearly the same speed (Ma, 1934).

2. There were three interglacial ages of warm climate. It is estimated that the first interglacial age lasted for 75,000 years, the second for 150,000 years and the third for 100,000 years. The Alluvial epoch is the fourth interglacial and it is only 10,000 years since it began. If the raised coral reef along the present strandline was formed during the warmer periods at the beginning of Alluvial epoch, the recent coral reef should have been formed for these several thousand years and this is highly possible, as it was proved by Vaughan's observation on the living corals (1923). According to his estimation, the coral *Orbicella annularis* may be able to form a reef of 6 meters in thickness in 1,000 years under the climate of Florida and the West Indies. And if this is admitted it should be more certain that during by far longer interglacial ages coral reefs were made.

3. Uro-sammyaku (Fig. 2, III), the most conspicuous raised barrier reef, might be formed during the second interglacial age which was of the longest duration.

4. A well developed terrace at Hamigo might be formed in the same period with Uro-sammyaku.

5. In the Prepleistocene epoch, there was long period of the warm climate. It is also possible that the coral flourished during this period.

6. It may be correctly recognized that Yoron Island, which is a peak of a great mountain range, underwent some uplift during each glacial age, when the mountain-building process was active (Minato, 1954).

7. The molluscan fossils found in these raised coral reefs are all recent. Accordingly, these coral reefs cannot be very old.

From these facts, the following conclusion may be inferred. The summit of the island, which had been under the sea-level, rose up to the depth favorable for the growth of corals at some time during the long Prepleistocene epoch, and there the coral built the first reef (Fig. 2, I). During the first glacial age the foundation was elevated, and the second coral reef (Fig. 2, II) was formed during the first interglacial age, then the third (III) during the second, the fourth (IV) during the third interglacial, the fifth (V) during the early Alluvial epoch and the sixth (VI), the present barrier reef, during these several thousand years.

Though the raised coral reefs in the third region do not show so beautiful arrangement as those in the second, it is sure that chronologically they must be the same; the topmost and the lowest raised coral reefs in this region being formed contemporaneously with the topmost and the lowest ones in the second region.

The raised coral reefs in the first region are scattered irregularly on the horizontal plane which makes us remind of the recent coral reefs which is being formed now on the horizontal sea bottom off Chabana.

RÉSUMÉ.

1. A new hypothesis has been advanced about the formation of the barrier reef. It was inferred that the barrier reef of Yoron Island was first formed along the depth of about 10 meters. It is due to the disturbance of the coral growth by stirring up of the sandy bottom by waves that the coral did not flourish in the shallow water, and it is due to the insufficiency of light that it did not flourish in the deep water. It must be noticed that the north-eastern part of the island, where the barrier reef is most beautifully represented, has a gentle dip and is accumulated with sand.

2. The sand brought up on the surface of the coral reef gives a profound effect to the association of shell bearing molluscs.

3. At least four uplifts of land and one lowering of sea-level were suggested by the investigation of arrangement of the raised coral reefs in Yoron Island, which were explained to be formed in Prepleistocene epoch, in three interglacial ages and in the Alluvial epoch. The shell bearing molluscs found in the raised coral reefs are all recent species. Accordingly, the raised coral reefs in Yoron Island cannot be formations of remote age.

ACKNOWLEDGEMENT

My cordial thanks are due to Mr. K. Nagai, the manager of the Museum of Kagoshima Prefecture, for giving me preliminary informations about Yoron Island and to Prof. Hatae and Mr. Ohba of the Geological Institute, as regards literatures and advices.

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